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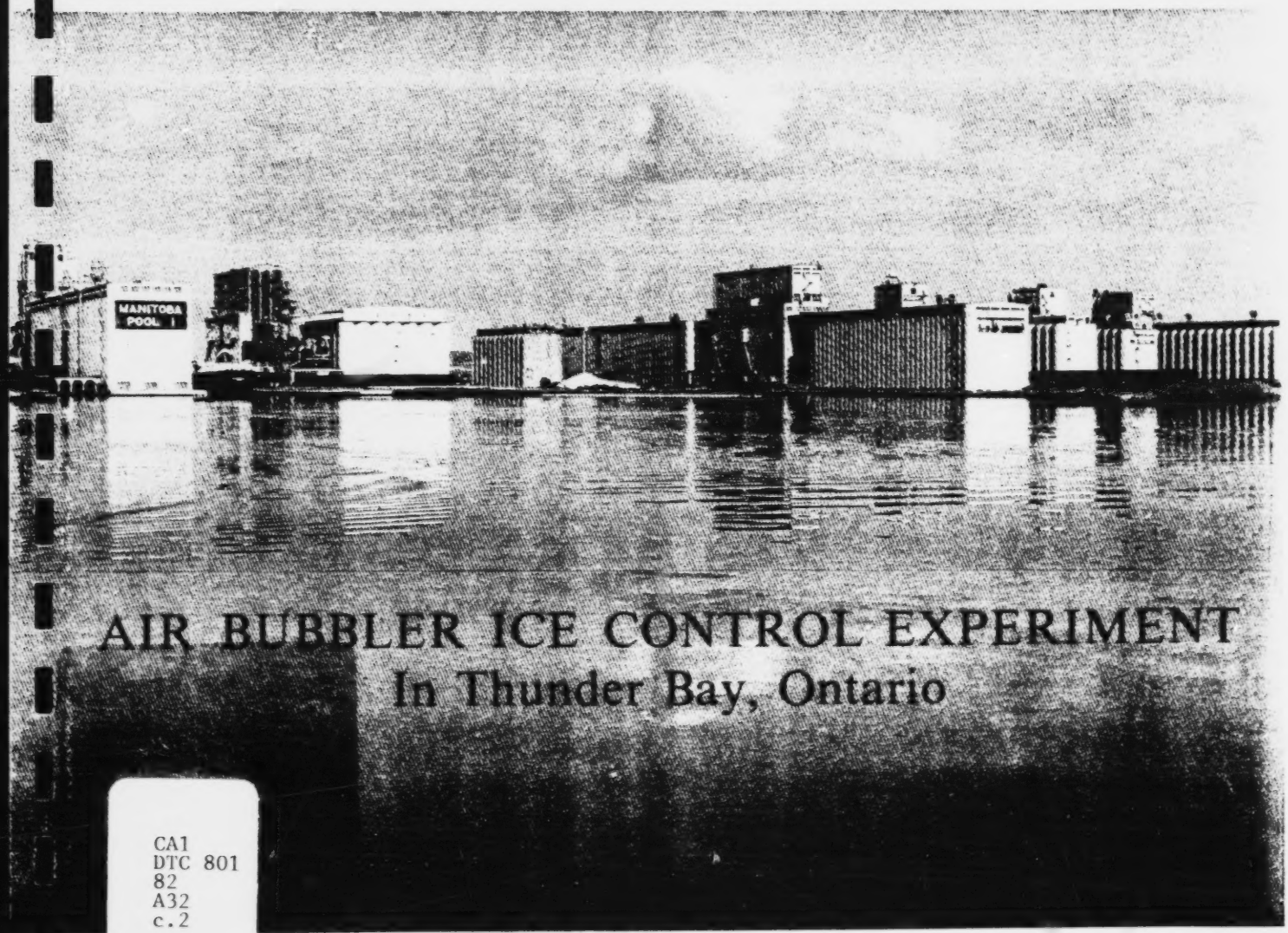

AIR BUBBLER ICE CONTROL EXPERIMENT
In Thunder Bay, Ontario

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VB COOK CO LIMITED CONSULTING ENGINEERS

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17. Abstract

The monitoring of the ice conditions in Saskatchewan Wheat Pool No. 7A grain elevator slip in Thunder Bay, Ontario, has provided data to relate ice growth with climatic conditions. Also, detailed monitoring of a bubbler system at this site has provided data to correlate the physical characteristics of the bubbler system with its ice melting capability.

A formula by Stephan to predict ice growth was modified and used with measured data to analyse the effect of cold weather on the performance of the bubbler system. A theoretical postulate developed by Ashton is used with measured data to define the bubbler ice melting capacity.

Combining the simultaneous effects of growth and melting, a practical technique to product air bubbler performance was developed. Specifically for a given bubbler configuration, initial ice thickness and climatic conditions, the procedure will predict the length of time required to operate the bubbler system to provide a desired area of open water in the slip.

This year, the slip was ready to receive a vessel on April 2, 1982, after the bubbler system had operated for approximately 20 days.

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17. Résumé

Le suivi de l'évolution de la couverture de glace au bassin n° 7, qui dessert les élévateurs à grain du Syndicat du blé de la Saskatchewan, a fourni les données nécessaires pour relier d'épaisseur de la glace avec les conditions atmosphériques. D'un autre côté, le suivi de l'exploitation expérimentale d'un système à diffuseurs d'air, dans ce même bassin, a permis d'établir la corrélation entre les caractéristiques du système et son aptitude à faire fondre la glace.

Les chercheurs ont modifé une formule théorique établie par Stephan pour la prévision de l'épaisseur de la glace et l'ont utilisée avec les données acquises pour analyser l'effet du froid sur le rendement du système étudié. Ils ont aussi défini l'aptitude du système à fondre la glace d'après les observations faites et les termes d'un postulat mathématique élaboré par Ashton.

Prenant en compte à la fois les facteurs de croissance et de fonte de la glace, ils ont mis au point une méthode empirique pour prédire la performance du système. La configuration de celui-ci, l'épaisseur initiale de la glace et les conditions atmosphériques étant données, cette méthode permet d'estimer le temps qu'il faudra au système pour libérer une superficie donnée du bassin.

En 1982, le bassin n° 7 a pu accueillir un premier bateau dès le 2 avril, le système à diffuseurs d'air ayant été mis en oeuvre environ 20 jours auparavant.

18. Mots-clés	19. Diffusion
Maîtrise des glaces, lutte contre les glaces dans les ports, système à diffuseurs d'air, technogénie des glaces	Le CDT dispose d'un nombre limité d'exemplaires

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MAY, 1982

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V. B. COOK CO. LIMITED

CONSULTING ENGINEERS

THUNDER BAY, ONTARIO

DISCLAIMER

The contents of this report reflect the views of the Engineer and not necessarily the official views or policies of the Transport Canada Transportation Development Centre.

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SUMMARY

Detailed monitoring of the Bubbler System has provided data to correlate the physical characteristics of the Bubbler System with its ice melting capability. Also, the monitoring of the ice conditions in Saskatchewan Wheat Pool No. 7A grain elevator slip has provided data to relate ice growth with climatic conditions.

The slip was ready to receive a vessel on April 2, 1982 after the Bubbler had operated about 28 days.

A formula by Stephan to predict ice growth was modified and used with measured data to analyze the effect of cold weather on the performance of the bubbler system. A theoretical postulate developed by Ashton is used with measured data to define the bubbler ice melting capacity.

Combining these simultaneous effects of growth and melting, a practical technique to predict air bubbler performance was developed. Specifically for a given bubbler configuration, initial ice thickness and climatic conditions, the procedure will predict the length of time required to operate the bubbler system to provide a desired area of open water in the slip.

It is concluded that line Bubbler Systems are a viable means of melting ice in grain elevator slips.

It is further recommended that future systems be fully engineered and monitored so that their design and performance could be optimized.

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1. INTRODUCTION

An air bubbler system was originally installed in 1979 in the slip beside Saskatchewan Wheat Pool grain elevator No. 7A. It has operated during the winter seasons of 1979/80, 1980/81 and 1981/82.

In order to evaluate the performance of the system, this study was undertaken. Operating data and technical considerations for this study are based on the system as it existed during the 1981/82 winter season.

The study was co-sponsored by the Lakehead Harbour Commission and Transport Canada Transportation Development Centre as part of a Task Force study investigating various techniques of ice control in the harbour at Thunder Bay.

This report describes the monitoring carried out and presents the data collected. The results are analyzed and compared with theoretical work published on the subject, and a technique to predict the length of time required to operate the bubbler system is developed.

V. B. Cook Co. Limited, Consulting Engineers, were engaged to provide appropriate monitoring and to report on the performance of the installed air bubbler system.

From previous work done by the Lakehead Harbour Commission, and after researching related ice technology publications, it was decided to measure and monitor the following parameters:

- air pressure and flow
- compressor power consumption
- slip water temperatures
- climatic conditions
- ice thickness growth and deterioration
- general observations during the operational period

2. MAIN TEXT

2.1 System

The air bubbler system flow sheet is shown on Drawing No. 500. Two 40 h.p. Grimmer Schmidt compressors, each with a rated capacity of 300 m^3/h of free air at a nominal operating pressure of 690 kPa gauge provide the compressed air supply.

The two compressors discharge to a 75mm pipe manifold and into a 0.28 m^3 receiver. The 75mm outlet from the receiver feeds four air metering stations, each connected to a branch of the system.

Details of the air metering station are shown on Drawing No. 501. Air from the receiver feeds a 75mm (3 inch) header and is split into four parallel branches. The air temperature is measured in the header. A condensate trap and drain valve are located at the bottom of the header for periodic cleaning.

Each branch of the air metering station is fabricated from a 50mm (2 inch) diameter pipe and includes a 50mm (2 inch) isolation valve, an annubar flow sensor device and a pressure regulating valve. A portable "Eagle Eye" flow meter connects to each annubar device. Each branch is connected to the distribution pipe consisting of two parts: the delivery section and the diffuser section. The delivery section consists of approximately 6m of 38mm diameter rubber hose and is connected to a vertical pipe attached to the side of the wharf. The vertical pipes are internally heat traced and carry the air approximately 10m from the top of the wharf to the bottom of the slip.

The diffuser sections are connected to the bottom of the vertical pipes and rest on the slip bottom. Each diffuser is made up of two parts. The first part is made from a 38mm diameter galvanized pipe with 0.79mm diameter holes drilled in the pipe wall at approximately 6.7m centres. The second part is made from a 25mm diameter galvanized pipe and has 1.59 mm diameter holes drilled in the pipe wall on 6.7m centres. The inshore diffusers are 330m long and the outshore diffusers are 292m long.

2.2 Procedure and Observations

2.2.1 General

In the fall of 1981 before freeze-up, the operation of the diffuser piping was checked. The system was turned on

and the bubble propagation from each orifice was observed. A rupture in the outshore diffuser leg was detected and subsequently repaired.

During the latter part of 1981, the air metering system was designed, fabricated and installed. The bubbler system operated intermittently from January 14, 1982 to February 14, 1982. During this time, the functions of the compressors and flow metering equipment were tested and adjusted as required.

The system was shut down from February 15th to February 27th and ice thickness measurements were taken to determine ice growth under the climatic conditions of that period.

The bubbler system was operated and monitored closely from February 27th to April 1st, 1982. During this period, ice deterioration was monitored in detail. Ice thickness measurements were taken until March 18th but were discontinued because of the potential hazard of open water and thin ice. Sequential photographs were used to monitor the ice deterioration throughout the period to April 1, 1982. The system was finally shut down on April 14, 1982 and the first vessel arrived in the slip on April 15, 1982.

2.2.2 Air Flow

The air flow in each diffuser branch was adjusted by the pressure regulating valves. An attempt was made to set and regulate the air flow in each branch at 127 m^3/h (standard air). On the overall average, this was achieved but it was found that the 0.28 m^3 surge tank was not large enough to smooth out the surges from the compressors. This caused individual branch flows to actually cycle from about 100 to 136 m^3/h (standard air).

Also, the pressure regulating valves were found not to operate consistently in this range. Small changes in setting were found to produce large changes in flow. The pressure gauges on the regulating valves gave incorrect readings, and a needle gauge was ultimately used in the rubber delivery hose to obtain reliable pressure data.

2.2.3 Climatic Conditions

The severity of the winter condition was established from meteorlogical data published by Environment Canada from Thunder Bay Airport. From the hourly temperature readings, the Freezing Degree Days (below 0°C) and Thawing Degree Days (above 0°C) were calculated from October 1, 1981 through to March 31, 1982. This detailed method of calculating Freezing and Thawing Degree Days was employed because it is more accurate than using the mean of the maximum and minimum daily temperatures as used by Environment Canada to calculate degree days.

There is generally a temperature difference between the lakeshore and the airport. Maximum and minimum daily air temperatures are recorded at the Water Pollution Control Plant (WPCP) near the waterfront. When comparing these maximum and minimums to the airport data, it can be seen that during winter months the average lakeshore temperature is somewhat warmer than the airport. However, for purposes of monitoring the bubbler system during March, this difference was assumed negligible.

It should be noted that statistics from 1941 to 1970 show that the total degree days below 0°C for winter seasons at the airport was 1511.2 compared to 1421.4 near the lakeshore. This represents an overall difference of about 6%.

2.2.4 Water Temperature

Water temperature measurements were taken at the bottom of the slip by lowering a thermometer through the ice. This was not a very sophisticated measurement but was taken to establish the water temperature at the diffuser discharge and hence used to measure the effectiveness of the bubbler system. It must be noted that no measurements were made to establish a thermal gradient in the slip nor to measure the total thermal reserve. The instrumentation required for such measurement was beyond the scope of work and the budget for this project.

2.2.5 Ice Thickness

A 34 station grid was established to measure ice thickness as shown on Drawing No. 502. The stations were determined on the following basis:

i Eleven stations were located along the centre line of the inshore centre slip diffuser pipe.

ii Five sets of stations were located perpendicular to the inshore wharf and centre slip diffuser lines.

iii Two stations were located away from the influence of the diffuser lines.

iiii One station was located at an open water break point (primarily used to measure ice growth).

The ice thickness measurement grid above the inshore diffuser legs was selected primarily for safety reasons. Personnel safety lines were attached to the wharf while working on the ice. This proved particularly useful when the ice thickness decreased to less than 100mm. It was assumed, when setting this grid, that the ice deterioration would be the same for the inshore and outshore diffuser legs, however, this was found to be incorrect as discussed later.

A chain saw was found to be the best method for measuring the ice thickness. The slot cut was just wide enough to insert the measuring wire with a perpendicular tang at the bottom. However, the slot was small enough so that in a short time it refroze completely to the current ice thickness and did not affect subsequent thickness measurements at the same location.

Although several methods using augers were tried, they were time consuming and caused incorrect and inconsistent readings. The most significant problem occurred when the auger broke through the ice. The downward force fractured ice from around the edge of the underside of the hole. This, of course, caused incorrect readings with the measuring wire. The chain saw, however, produced no localized fracture on the underside of the ice and provided a square edge to catch the measuring wire tang.

Ice thickness measurements were suspended on March 18th because of the potential hazard of open water and thin ice.

Photographs of the ice surface were taken at regular intervals from March 1, 1982 to April 1, 1982. These were used to estimate the rate of ice deterioration after it was too dangerous to take ice thickness measurements on the ice.

2.2.6 Power Consumption

It was originally intended to measure the power consumed by recording voltage, amperage and power factor on each compressor motor. However, the required instrumentation and recording equipment proved to be too expensive to fit within the project budget. Periodic hour meter readings on the motors were taken and used to estimate power consumption during the test period at approximately 1240 kwh/day.

2.3 Theoretical Considerations

2.3.1 Seasonal Ice Growth

Natural ice growth can be predicted using Stephan's formula as follows:

$$h = 0.0341 \times \alpha \times \sqrt{D} \qquad \ldots \quad (1)$$

where h = ice thickness (meters)

α = coefficient

D = cumulative freezing degree days (°C-day)

Rearranging Equation (1);

$$\alpha = \frac{h}{0.0341 \sqrt{D}} \quad \ldots (1a)$$

Using the results from measured data to March 31, 1982;

$$D = 1318°C\text{-day}$$

when $h = 0.53$ m

$$\alpha = \frac{0.53}{0.0341 \sqrt{1318}} = 0.43$$

when $h = 1.0$ m

$$\alpha = \frac{1.0}{0.034 \sqrt{1318}} = 0.81$$

Therefore α (average) $= \frac{0.43 + 0.81}{2} = 0.62$

This calculated value, using observed measurements, is in close agreement with the value suggested by Arctec Canada Limited in their draft report dated March 22, 1982. The co-efficient is dependent on many variables including snow cover, wind velocity and hours of sunshine. All of these factors varied significantly throughout the slip area and can explain the range of the results obtained.

2.3.2 Ice Growth with Initial Ice Thickness

The rate of ice growth decreases as the ice thickness increases since the ice develops an insulating layer between the water and the air. In order to analyze this phenomena, a modified version of Stephan's formula was created:

$$n = 1.34 \times X \times \sqrt{D} \quad \ldots (2)$$

where n = ice thickness at any time in meters

X = function (t_i, α)

t_i = initial ice thickness in meters

α = Stephan's coefficient

D = cumulative freezing degree days (°C-day)

From this, a rate of change of ice thickness can be shown as:

$$\frac{dn}{dt} = 1.34 \sqrt{D} \frac{dX}{dt} \text{ (m/day)} \quad \ldots \quad (3)$$

Rearranging Equation (3);

$$\frac{dX}{dt} = \frac{dn/dt}{1.34 \sqrt{D}} \quad \ldots \quad (3a)$$

Using the ice thickness measurements from February 15 to February 25, 1982, the rate of growth (dn/dt) was calculated for various initial ice thicknesses. Using the corresponding cumulative freezing degree days for the period, the dX/dt can be calculated for a variety of measured conditions. The results of these calculations are plotted on Drawing No. 504.

From this plotted data, a "best fit" curve is drawn, representing the relationship between the dX/dt and the initial ice thickness.

Using the values of dX/dt from the graph on Drawing No. 504, Equation (3) can be used to predict ice growth at the Saskatchewan Wheat Pool slip for any freezing degree day conditions and initial ice thickness. This procedure was used to develop a family of curves for initial ice thicknesses varying from 127mm to 890mm and cumulative freezing degree days up to 200°C-day. These results are shown on Drawing No. 505.

2.3.3 Ice Melting Capacity of Bubbler System

A technical paper entitled "Air Bubbler Systems to Suppress Ice" by George D. Ashton, describes an analytical procedure to predict the effectiveness of a bubbler system under various physical conditions.

It must be noted that this approach assumes the air temperature above the ice is constantly at 0°C, and does not take into account any retarding effect on the melting rate when the air temperatures are below freezing. This effect will be analyzed later in the discussion.

The following analysis follows the procedure outlined by Mr. Ashton:

Using data from the outshore centre slip diffuser line at Saskatchewan Wheat Pool, No. 7A Grain Elevator slip:

Air Delivery	=	127 m^3/h (standard air)
Line Length	=	290m
Water Temperature	=	1°C (at bottom of slip)
Submergence Depth	=	8m (27 feet)

The air discharge rate per unit length of diffuser pipe is given by:

$$Qa = \frac{127}{290} = 0.43 \text{ m}^3/\text{h/m}$$

Assuming a linear variation in water temperature from the bottom of the slip to the undersurface of ice, the water temperature of the impinging flow is given by:

$$Tw = \frac{Tam}{2} = \frac{1°C}{2} = 0.5°C$$

Where Tam = water temperature at level of diffuser pipe (°C)

The width of the impingement region on the undersurface of the ice is given by:

$$2b = 2(H + X_o)\ C_c\ \frac{(Qa)}{(3600)}^{0.15}$$

where H = Submergence depth = 8m

X_o = Vertical co-ordinate constant = 0.8m (by Ashton)

C_c = Experimental coefficient = 0.182 (by Ashton)

Q_a = Diffuser unit discharge rate = 0.43 m³/h/m

Therefore the width of the impingement region is:

$$2b = 2(8 + 0.8)\ 0.182\ \frac{(0.43)}{(3600)}^{0.15}$$

$$= 0.83\text{m}$$

The heat transfer rate on the undersurface of the ice is given by: $q_{wb} = H_b\ (T_w - T_m)$

where H_b = Heat transfer coefficient in the impingement region

= 700 W/m²°C (from figure 11 - Ashton)

T_w = 0.5°C

T_m = Melting point temperature of ice = 0°C

Therefore $q_{wb} = 700\ (0.5 - 0) = 350$ watts/m²

The rate of melting ice at the centreline of the impingement region is given by:

$$\frac{dn}{dt} = \frac{q_{wb}}{f_i \lambda}$$

where dn/dt = ice melting rate - (inches per day)

q_{wb} = heat flux = 350 watts/m²

f_i = mass density of ice = 916 kg/m³ (by Ashton)

λ = heat of fusion of ice = 3.34×10^5 J/kg (by Ashton)

Therefore melting rate: $\frac{dn}{dt} = \frac{350}{916 \times 3.34 \times 10^5}$

$= 1.14 \times 10^{-6}$ m/s

100mm/day

The rate of melting decreases with the distance outward from the centreline of the impingement region. Ashton shows a relationship between the heat transfer rate and the distance from the impingement region (see figure 12 - Ashton). From this relationship, ice melting rates were computed for the Saskatchewan Wheat Pool system for various distances from the impingement region. The results are shown on Drawing No. 506.

The calculations presented above are valid for conditions when the ice is not thickening, in other words, when the air temperature above the ice surface is near 0°C. If the top surface temperature is significantly below freezing, the ice only melts on the undersurface until an equilibrium thickness is attained. At this point, the heat transfer to the undersurface of the ice from the bubbler system exactly equals the heat transfer by conduction through the ice due to the climatic condition. The resulting melting rate is zero. This phenomena was observed at the beginning of the second week in March. Minimum temperatures dropped to about -27°C from March 7th to 9th, resulting in average daily temperatures approximately -18°C. Previous to this, on March 6th there was open water at one location and a thickness of 25mm measured at another. However, by March 8th, the open water had frozen to a thickness of 95mm and the 25mm ice had increased to 300mm.

Using this condition of -18°C and a heat flux of 350 watts/m² as calculated above, Ashton predicts the equilibrium ice thickness should be about 150mm (see Figure 13 - Ashton). Although this agreement between observed data and theory in

this single isolated case cannot be considered conclusive, it does support and provide a measure of confidence in the calculated heat flux of 350 watts/m^2 for the system in the impingement area.

3. RESULTS

3.1 Climatic Conditions

From meteorlogical data from the Thunder Bay Airport published by Environment Canada, the Freezing Degree Days (FDD) below 0°C and the Thawing Degree Days (TDD) above 0°C were calculated and are summarized as follows:

MONTH	DAYS	FDD	TDD	CUMULATIVE TOTAL
October	31	- 18	+147	+ 129
November	30	- 41	+ 64	+ 23
December	31	- 284	0	- 284
January	31	- 640	0	- 640
February	28	- 365	+ 1	- 364
March	31	- 192	+ 10	- 182
TOTALS		-1540	+222	-1318

The daily FDD and TDD calculated from Environment Canada are tabulated on the next page.

3.3 Water Temperature

The water temperature at the bottom of the slip was found to be consistently about 1°C. The thermometer used can be considered accurate and readable to approximately plus or minus 0.3°C.

3.4 Ice Growth

The ice growth from the start of the winter season to March 1, 1982 varied from 0.53m in the centre area of the slip to about 1.0m beside the wharf. These measurements were taken in areas not affected by the periodic operation of the bubbler system prior to March 1st. Some thicker ice measurements were noted directly adjacent to the wharf but were likely due to localized cold flux from the sheet pilings alongside the wharf. These measurements were disregarded in the results and analysis.

Ice growth was measured when the bubbler system was shut down from February 15 to 25, 1982. These measurements are tabulated on the upper portion of Drawing No. 503.

3.2 MONTHLY SUMMARY*

Freezing Degree Days (FDD) below 0°C and Thawing Degree Days (TDD) above 0°C calculated from hourly temperature readings by Environment Canada at Thunder Bay Airport

Thunder Bay Winter Season 1981/82

DAY	OCTOBER	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH
1	+ 1.4	+ 6.1	- .7	-24.6	-15.6	- 8.0
2	+ 2.3	+ 4.4	- .6	-12.5	-13.1	-13.8
3	+ 4.1	+ 5.2	- 2.3	-11.7	-24.5	-16.4
4	+ 7.8	+ 3.2	- 3.8	-17.2	-25.5	-11.9
5	+ 8.7	+ 4.9	- 6.3	-15.9	-26.1	-10.5
6	+ 7.6	+ .7	- 2.6	-21.1	-23.2	- 9.1
7	+ 5.9	+ .8	- 1.5	-23.8	-15.2	-17.7
8	+ 5.1	+ .8	- 5.9	-27.1	-19.0	-19.3
9	+ 8.0	- 2.1	-11.6	-31.7	-22.5	-15.7
10	+ 8.0	+ 1.1	-13.0	-27.9	-20.3	- 5.9
11	+ 8.2	- 1.3	-11.6	-15.8	-14.1	- 6.5
12	+ 8.9	+ 5.4	- 2.5	-21.5	-18.3	- 4.5
13	+10.5	+ 5.0	- 2.9	-24.4	-18.1	- 1.3
14	+10.4	+ 6.9	- 7.3	-14.3	-16.0	- 2.9
15	+ 5.9	+ 7.0	-10.0	-13.7	- 3.5	- .1
16	+ 6.6	+ 6.8	-13.0	-30.9	- 9.4	+ .4
17	+ 8.6	+ 3.4	-17.0	-32.4	- 4.8	+ 1.2
18	+ 1.4	- .1	-12.7	-28.8	+ 0.0	- 1.4
19	- 1.3	- 3.2	-17.6	-14.4	+ 0.8	- 8.0
20	+ .7	- 4.4	-11.5	-25.2	+ 0.5	- 4.6
21	- 3.3	- 6.3	- 1.5	-24.7	- 3.7	+ .7
22	- 2.2	- 9.0	- 2.7	-19.2	- 1.8	- 1.9
23	- 4.7	- 5.2	- 8.5	-16.3	-11.3	- 1.7
24	- 2.1	- 2.7	-15.8	-24.5	-11.2	+ .5
25	- 1.1	+ .3	-14.6	-22.4	-15.5	- 5.4
26	- 3.5	+ 1.7	-16.2	-21.1	- 8.2	-11.1
27	+ 2.8	- .7	- 2.5	- 4.0	-13.9	-11.3
28	+ .3	- 2.8	-12.1	-13.2	-10.3	- 3.2
29	+ 5.9	- 1.7	-18.4	-17.0		+ 2.9
30	+ 7.8	- 1.3	-22.6	-17.6		+ 2.0
31	+10.8		-14.6	-25.0		+ 2.4
TOTAL						
FDD	-18.2	-40.8	-283.9	-639.9	-365.1	-192.2
TDD	+147.7	+63.7	0	0	+ 01.3	+ 10.1

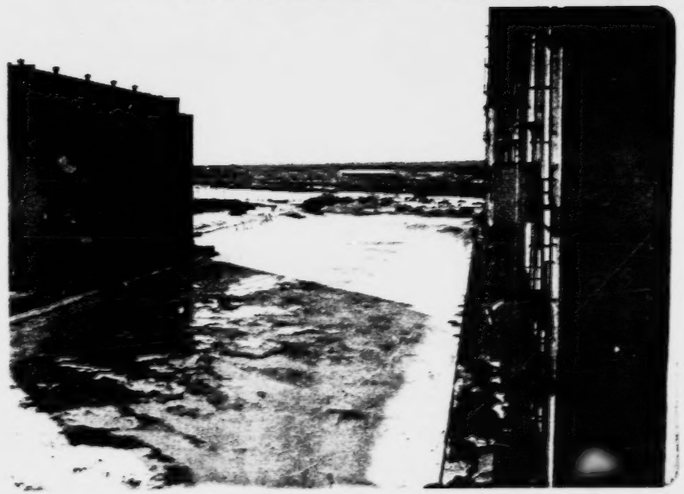
3.5 Ice Deterioration

The ice thickness measurements taken between March 1 and March 18, 1982 to monitor ice deterioration are recorded on Drawing No. 503. The measurements show that only a small portion of the inshore diffuser lines operated properly. However, by analyzing the stations that did show open water, a rate of ice deterioration was determined and correlated to the climatic conditions during that period.

Comparing ice thickness with climatic conditions, an average ice deterioration rate of about 36mm per day during a period when the cumulative Freezing Degree Days totalled 65°C-day and about 20mm per day when the cumulative Freezing Degree Days totalled 150°C-day.

It is interesting to note when comparing the climatic data with the ice thickness measurements that the bubbler system became stalled shortly after March 6th. At that point, the ice deterioration rate dropped to zero. In other words, an equilibrium point was reached and the ice growth rate, due to climatic conditions, exactly balanced the bubbler system melting rate capability. Subsequently, during very cold weather around March 8th, the effect of climatic conditions overpowered the capability of the bubbler system and the ice thickness actually grew. Then, as the weather warmed between March 9th and 10th, an equilibrium state was again reached, and by March 11th, ice deterioration was again underway.

The overall ice deterioration of the inshore and outshore diffuser lines was monitored using sequential photographs. A representative selection of these photos are shown in Figure 1 through Figure 6.



MARCH 1, 1982

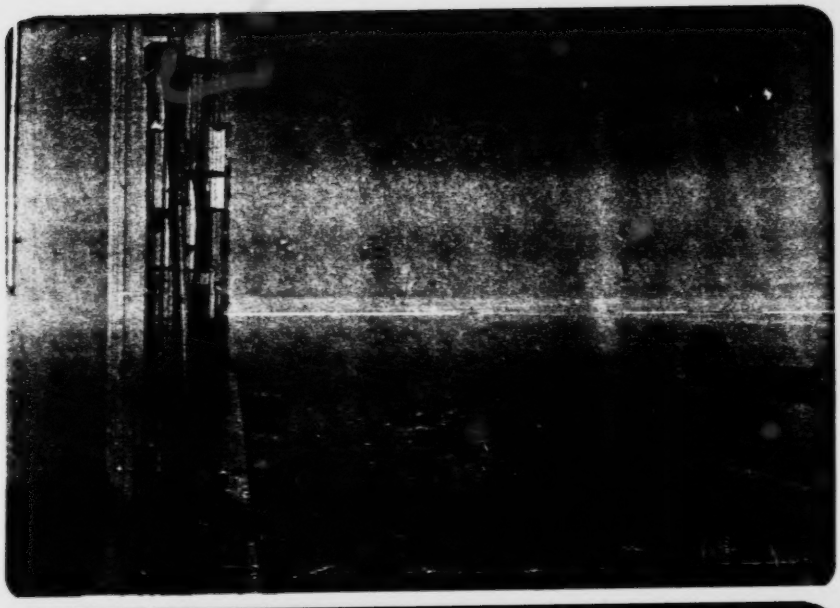
- small pockets of ice deterioration have appeared along the wharf, both inshore and outshor
- no significant deterioration from mid slip bubbler diffusers

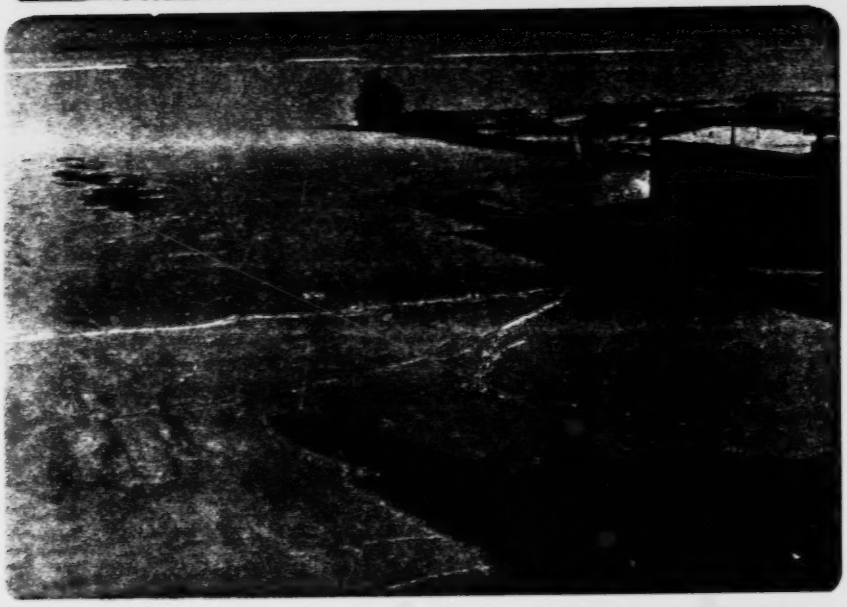
MARCH 1, 1982
Figure 1

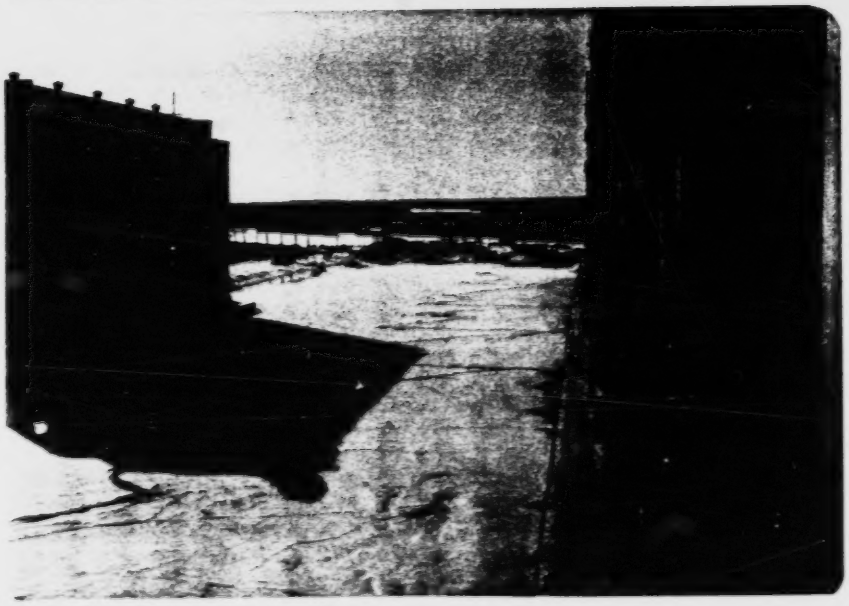
MARCH 5, 1982

- wharf ice deterioration becoming well established inshore and outshore
- still no significant ice deterioration from mid-slip diffusers

MARCH 5, 1982
Figure 2



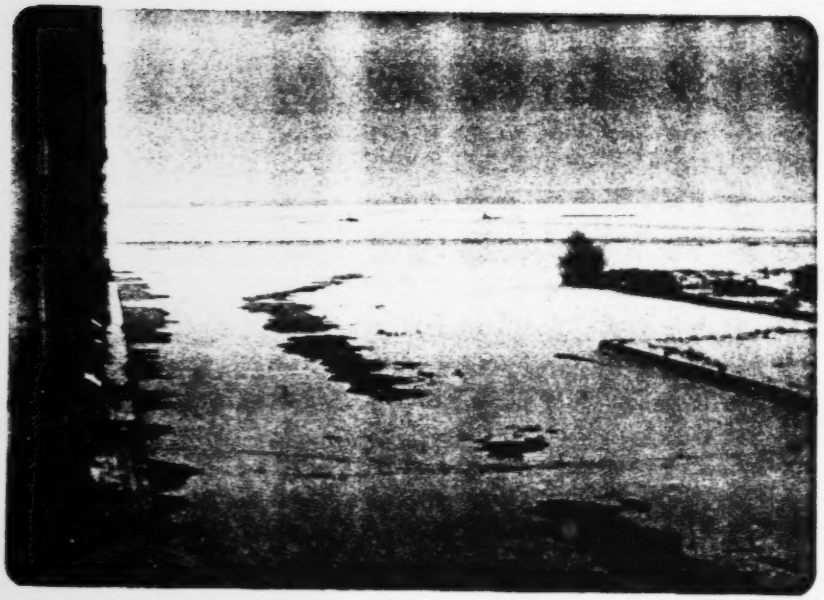


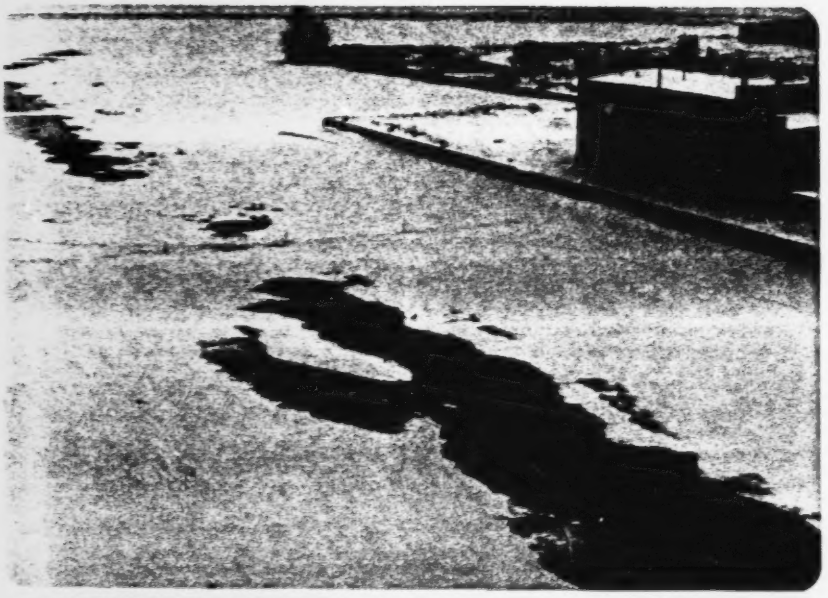


MARCH 11, 1982

- a recent snowfall serves to provide visual contrast between solid ice and open water
- wharf ice deterioration steadily increasing inshore and outshore
- midslip Bubbler has broken through inshore and outshore

MARCH 11, 1982
Figure 3





MARCH 18, 1982

- wharf ice deterioration steadily increasing inshore and outshore
- midslip Bubbler is becoming well established for approx. half its length inshore and its length outshore

MARCH 18, 1982
Figure 4

MARCH 29, 1982

- wharf and mid slip ice deterioration areas are about to join. Ice between the two diffusers is very thin
- inshore Bubblers have not been as effective as outshor

MARCH 29, 1982
Figure 5

APRIL 14, 1982

- slip completely open on Saskatchewan Pool 7A side and has berthed first ship of 1982 season

APRIL 15, 1982
Figure 6

The photographs show the outshore diffuser lines performed very well. It took about 10 days for the outshore centre diffuser to first show open water. The width of open water grew to about 6m by the 18th day and to about 14m on the 29th day. Using the average ice thickness of 0.53m at the slip centre, this represents an overall ice deterioration rate of approximately 50mm per day at the centre of the bubbler impingement region.

The photographs confirm the comments made above that only some sections of the inshore centre slip diffuser line operated properly. From the photographs, it is interesting to note that an abandoned elevator structure on the south side of the slip sheltered the centre slip diffuser line from sunlight most of the day. This observation is made in passing only and no measured data supports a suggestion that this contributed significantly to the poor performance of the inshore diffuser.

4. CONCLUSIONS

The overall ice deterioration is dependent on the melting capacity of the bubbler system and the climatic conditions. This relationship is expressed by:

NET ICE DETERIORATION = BUBBLER CAPACITY ± CLIMATIC CONDITIONS

When the temperature directly above the ice is greater than 0°C, the climatic condition assists the bubbler system and when it is less than 0°C, it retards the bubbler effect.

To estimate the number of days required to operate the bubbler system prior to the start of shipping season, the above relationship was used with the data presented in this report and is summarized on Drawing No. 507.

This graph is based on the volume of ice to be melted for various initial thicknesses at the centre of the slip and is premised on the following:

- The ice is approximately twice as thick near the wharf as it is in the centre of the slip (measured 0.53m at the centre and 1m beside the wharf).
- Normal climatic conditions for Thunder Bay during the month of March (historically a mean normal daily temperature of -6°C with cumulative Freezing Degree Days equal to 190°C-day).
- A 27m wide channel of open water is desired by April 1. (It is anticipated some floating ice may be present but will not affect vessel movement).
- Two diffuser lines are used in parallel at the bottom of the slip and have a system capacity similar to the system tested.

To demonstrate the use of the graph shown on Drawing No. 507, suppose an elevator slip in Thunder Bay has a 330 m^3/h (standard air) air supply with a total 915m diffuser line, and the ice thickness at the centre of the slip is measured at 0.5m on the first day of March.

The air discharge rate is calculated:

$$Q_a = \frac{330}{915} = 0.36 \ m^3/h/m$$

From Drawing No. 507, it can be estimated that about 28 days will be required to open the slip. If a vessel is scheduled to arrive on April 1st, the bubbler system should be turned on no later than March 3rd.

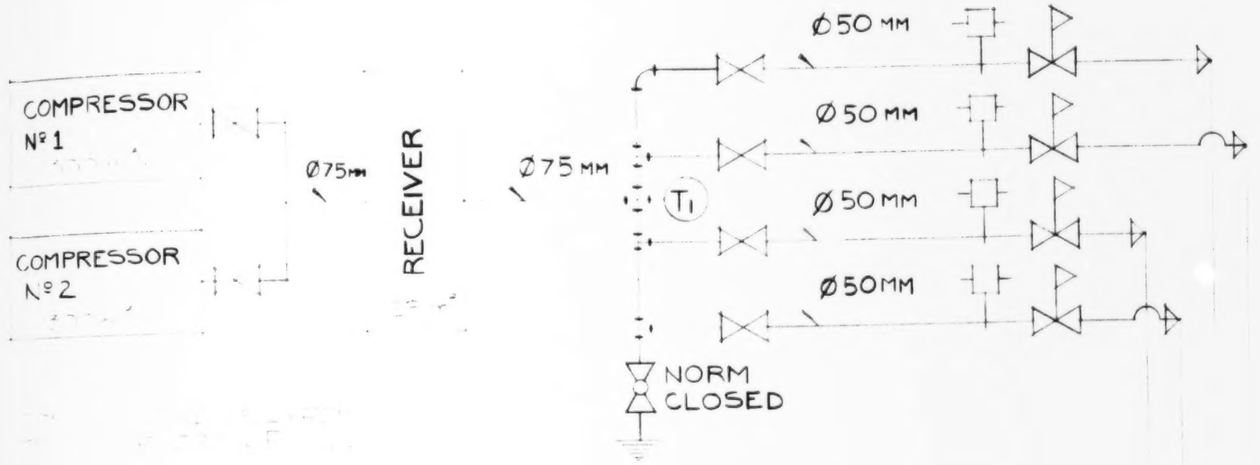
5. REFERENCES

1. Technological Alternatives to the Use of C.C.G.S. Icebreakers at Thunder Bay Harbour, Abdelnour, R. Arctec Canada Ltd. Draft March 22, 1982.

2. Air Bubbler Systems to Suppress Ice. U. S. Army Cold Regions Research and Engineering Laboratory. Ashton, G. D. September, 1974.

3. Air Bubbler Ice Control Experiment in Thunder Bay. Hill, J. E., P. Eng., May, 1980.

4. Normal Freezing and Thawing Degree-Days for Canada 1931 - 1960. Boyd, D. W. Environment Canada, Atmospheric Environment, Downsview 1973.

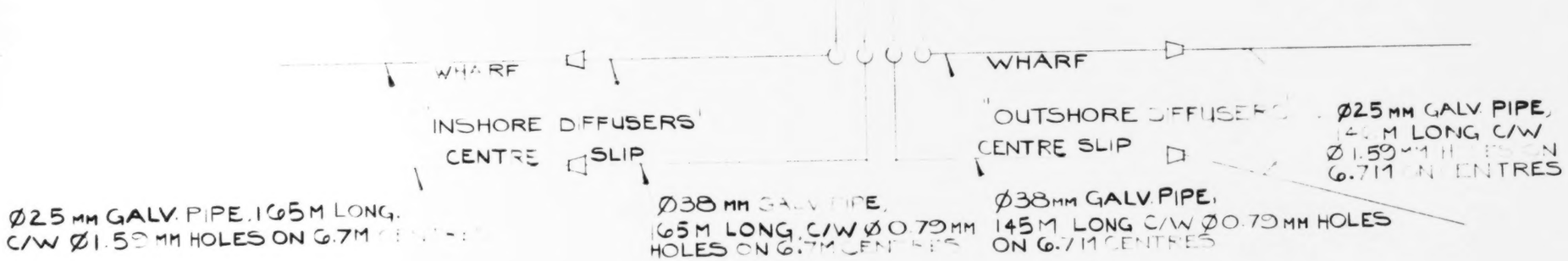


ELEVATION - COMPRESSOR METER EQUIP

LEGEND

- GATE VALVE
- PRESS. REGULATING VALVE
- BALL VALVE
- ANNUBAR FLOW METER
- T1 DIAL THERMOMETER
- TO DRAIN

Ø38mm RUBBER HOSE

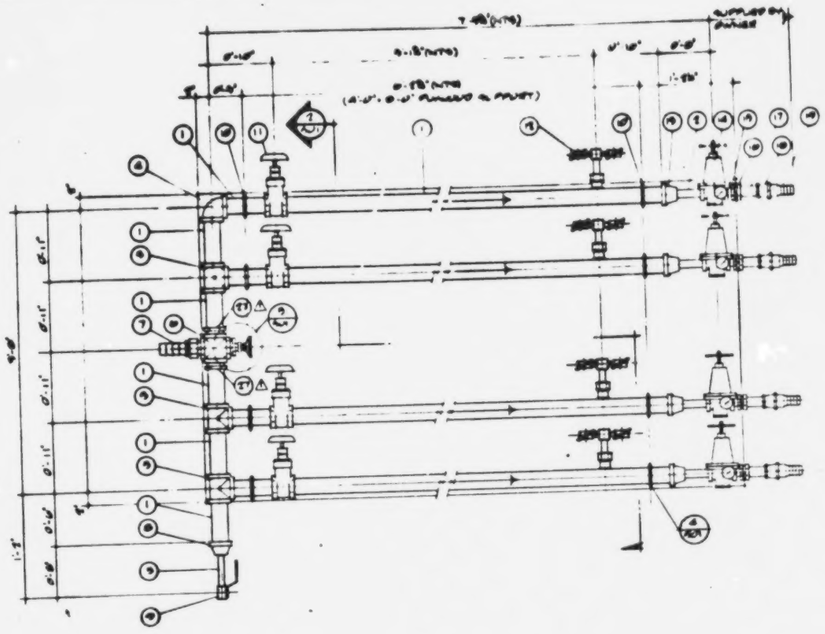

WHARF
INSHORE DIFFUSERS
CENTRE SLIP
Ø25 MM GALV. PIPE, 1.65 M LONG. C/W Ø1.59 MM HOLES ON 6.7M
Ø38 MM GALV. PIPE, 1.65 M LONG C/W Ø0.79MM HOLES ON 6.7M CENTRES
WHARF
OUTSHORE DIFFUSERS
CENTRE SLIP
Ø38MM GALV. PIPE, 1.45 M LONG C/W Ø0.79 MM HOLES ON 6.7 M CENTRES
Ø25 MM GALV. PIPE, 1.45 M LONG C/W Ø1.59 MM HOLES ON 6.7 M CENTRES

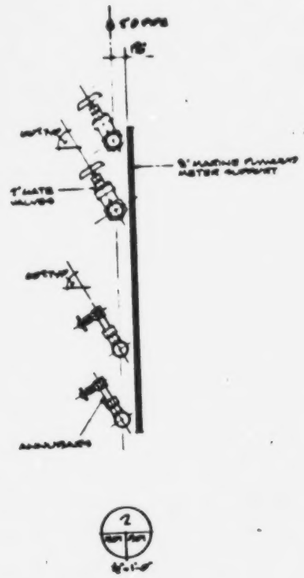
PLAN - SASKATCHEWAN WHEAT POOL 7A SLIP

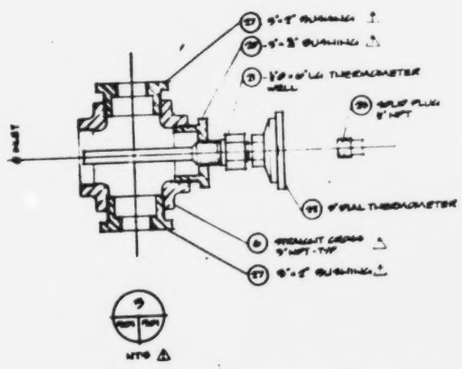
N.B. COOK CO. LIMITED
CONSULTING ENGINEERS
THUNDER BAY, ONTARIO

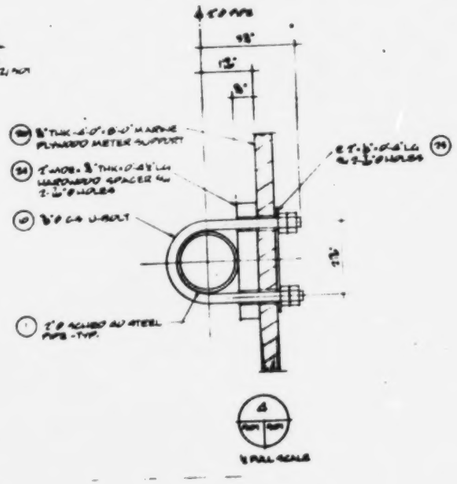
BUBBLER SYSTEM - FLOW DIAGRAM - SLIP 7A

DRN	J.H.	CHKD		SCALE	NTS	500
APP		DATE	3/81	PROJ Nº	80-211-01	









BILL OF MATERIAL

MK	QTY REQ'D	DESCRIPTION	REMARKS
1		2"Ø SCHEDULE 40 STEEL PIPE	
2		1"Ø SCHEDULE 40 STEEL PIPE	
3		½"Ø SCHEDULE 40 STEEL PIPE	
4	1	2" NPT CLASS 125 STANDARD ELBOW	
5	4	2" NPT CLASS 125 STANDARD BLACK TEE	
6	1	2" NPT CLASS 125 STANDARD BLACK STRAIGHT COUPLING	
7	1	2" NPT MALE PIPE THREAD TO HOSE NIPPLE (GARDEN HOSE)	
8	1	2"Ø NPT CLASS 125 STANDARD BLACK CONCENTRIC RED.	
9	1	2" NPT WAFER STYLE 200 SCREWED END BALL VALVE	BR.
10	1	2" NPT WAFER STYLE BUTTERFLY VALVE C/W U-BOLT, LUG WAFER	316 SS TANGENT
11	4	2" NPT 125# BRONZE GATE VALVE C/W HANDWHEEL	
12	4	MANOMETER NOZZLE ASME 79, 2" SCHED 80 C.S. C/W CAP	BY OWNER
13	4	2"×1" NPT CLASS 125 STANDARD BLACK CONCENTRIC REDUCER	
14	4	PRESSURE REGULATOR	BY OWNER
15	4	1" NPT MALE SPUD	" "
16	4	1½"×1" NPT REDUCING COUPLING	" "
17	4	1½"Ø PIPE	" "
18	4	1½"×1½" NPT REDUCER	" "
19	4	1½" DISCHARGE HOSE NIPPLE - MALE NPT	
20	1	2"×2" NPT CLASS 125 STANDARD BLACK HEX BUSHING	
21	1	SEPARABLE THERMOMETER WELL, 1½" O.D. x 4" LONG 2" NPT THREAD, TAYLOR No. 1-17, STAINLESS STEEL	BY OWNER
22	1	9" DIAL BIMETAL THERMOMETER, 2 mm DIA., 2" NPT CONNECTION, RANGE 0/120 F, TAYLOR WATER STD MODEL 6121	BY OWNER
23	1	½" NPT SOLID PLUG	
24	8	1'-3"×0'-0½" LG HARDWOOD SPACER w/ 2 ⅞"Ø HOLES	
25	8	2 2"×3"×0'-6" LG w/ 2 ⅞"Ø HOLES	
26	1	¾" THK. 4'-0" × 8'-0" MARINE PLYWOOD	
27	2	2"×2" NPT, CLASS 125 STANDARD BLACK HEX BUSHING	

1 AIR METERING STATION 1½"=1'-0"

NOTE: 2" GATE VALVES AND ANNUBARS SHOWN IN VERTICAL PLANE. FOR ACTUAL POSITION SEE DET. 2, NOT

2 NTS

3 ½ FULL SCALE

4 ½ FULL SCALE

AIR METERING STATION

BUBBLER SYSTEM FOR LAKEHEAD HARBOUR SEDIMENTATION

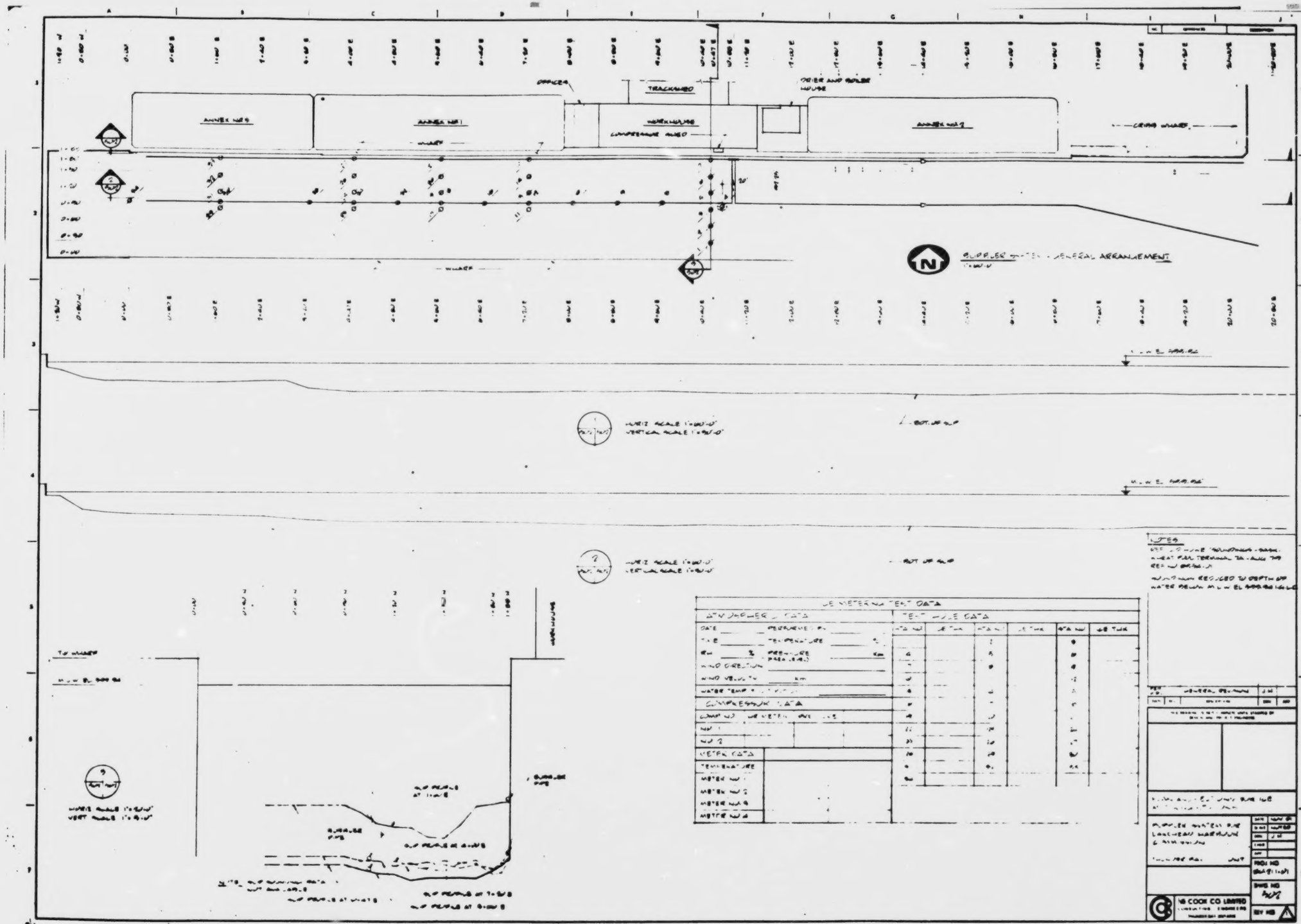
SHEET ONE OF ONE SHEET

W. F. COOK CO. LIMITED CONSULTING ENGINEERS

PROJ. NO. 69-211-69

DWG. NO. 501

REV NO.


OFFICES
TRACKMOBILE
ANNEX No 5
ANNEX No 1
WORKSHOP
CONFERENCE ROOM
ANNEX No 2
CRANE WHARF
WHARF
SUPPLIER WATER - GENERAL ARRANGEMENT
HORIZ SCALE 1:100-0"
VERTICAL SCALE 1:50-0"
TO WHARF
HORIZ SCALE 1:50-0"
VERT SCALE 1:10-0"
NOTES
SUPPLIER WATER DATA
TEST HOSE DATA
METER DATA

ICE THICKNESS TEST HOLE DATA (METERS)

TEST DATE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	CTL STA	WTR TEMP
FEB 15/82	*.863	.591	.229	.127	.260	.375	.216																														
FEB 18/82	.902	.610	.248	.184	.267	.362	.254										.438		.476	.692	.610								.489		.508	.635	*.864		.584	—
FEB 22/82	.902	.622	.248	.165	.311	.438	.273	.356	.241	.267		.337				.324		.406				.457						.470	.470	.433	.521	.622	*.864	.629	.668	0.0°
FEB 25/82	.933	.635	.356	.216	.330	.470	.279	.400	.273	.298	.514	.267	.400	.616	.216	.343	.546	.495	.489	.705	.502	.508	.540	.572	.578	.629	.203	.470	.502	.476	.533	.648	.876	.648	.673	1.1°
MAR 1/82	.940	.610	.286	.203	.318	.464	.178	.311	.178	.241	.514	.330	.406	.610	.171	.318	.527	.495	.527	.737	.610	*	.559	.546	.572	.597	.089	.483	.419	.470	.495	.673	.508	.495	.699	1.1°
MAR 3/82	*.914	.673	.331	.114	.343	.406	.9	.305	.52	.229	.508	.330	.406	.457	.152	.305	.546	.572	.660	.711	.635	.470	.584	.521	.584	.584	.127	.483	.394	.508	.521	.686	.102	.508	.711	1.7°
MAR 5/82	*.914	.622	.343	.064	.343	.419	.191	.311	.051	EQUIPMENT BREAKDOWN																												
MAR 6/82	*.914	.00	.305	.025	.330	.400	.165	.267	.000	.203	.508	.305	.381	.635	.076	.203	.559	.508	.533	.762	.610	.508	.533	.521	.559	.597	.076	.533	.419	.508	.508	.686	.889	.152	.762	1.7°
MAR 8/82	*.914	.635	.318	.318	.356	.419	.140	.305	.096	.241	.514	.318	.381	.635	.033	.152	.552	.508	.552	.749	.737	.457	.565	.571	.559	.603	.102	.508	.451	.514	.540	.686	.345	.146	.775	1.7°
MAR 11/82	*.914	.635	.356	.051	.381	.432	.127	.305	.000	.191	.533	.318	.394	.643	.089	.076	.559	.508	.584	.762	.508	.483	.635	.521	.584	.635	.076	.533	.432	.533	.584	.724	.933	.102	—	1.4°
MAR 15/82	*.914	.660	.343	.000	.330	.381	.000	.000	.000	—	.521	.051	.420	.600	.000	.000	.546	.508	.584	.737	.254	.457	.584	.597	.603	.635	.000	.483	.533	.559	.603	.641	.730	.076	—	—
MAR 18/82	*.914	.686	.305	.000	.350	.406	.000	.000	.000	.000	.483	.076	.381	.660	.000	.000	.508	.559	.559	.762	.432	.076	.584	.559	.584	.660	.000	.432	.533	.559	.610	.711	.000	.000	—	—

NOTE
1. TEMPERATURE 0 °C

NOTES
* STATION DESTROYED

REVISIONS:
CONVERTED TO METRIC
DEC. 82

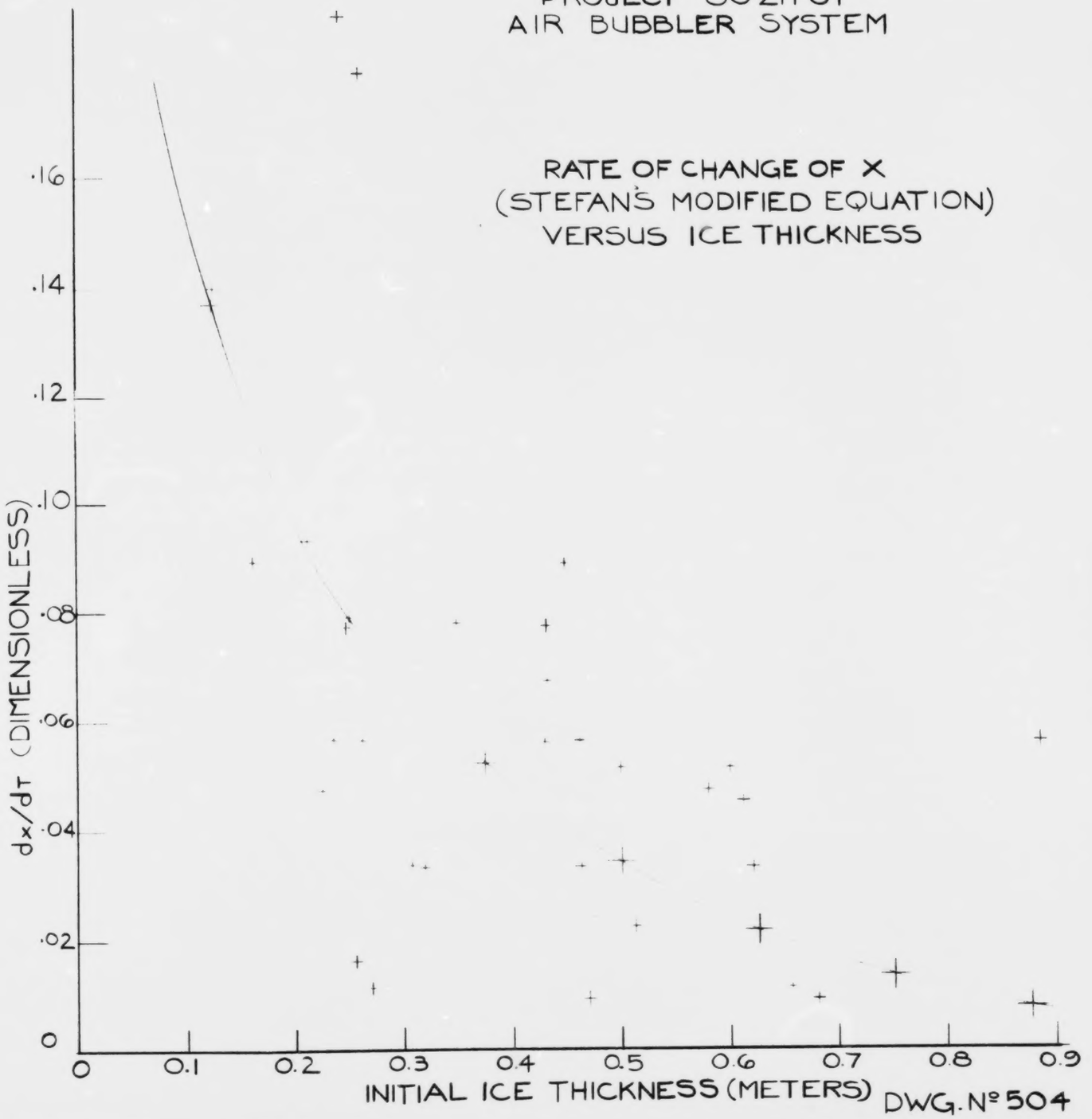
V.B. COOK CO. LIMITED
CONSULTING ENGINEERS
THUNDER BAY, ONTARIO

BUBBLER SYSTEM - TEST HOLE DATA - SLIP 7A

DRN	BWR	CHKD		SCALE	NTS	DWG No
APP		DATE	DEC/82	PROJ No	80-211	503

PROJECT 80-211-01
AIR BUBBLER SYSTEM

RATE OF CHANGE OF X
(STEFAN'S MODIFIED EQUATION)
VERSUS ICE THICKNESS



DWG. Nº 504

RATE OF GROWTH
VS FREEZING
DEGREE DAYS

PROJECT 80-21-01
AIR BUBBLER SYSTEM

INITIAL ICE THICKNESS

ti = .127 m

ti = .25m

ti = .38 m

ti = .50m

ti = .63 m

ti = .76 m

ti = .89 m

RATE OF ICE GROWTH (MM/DAY)

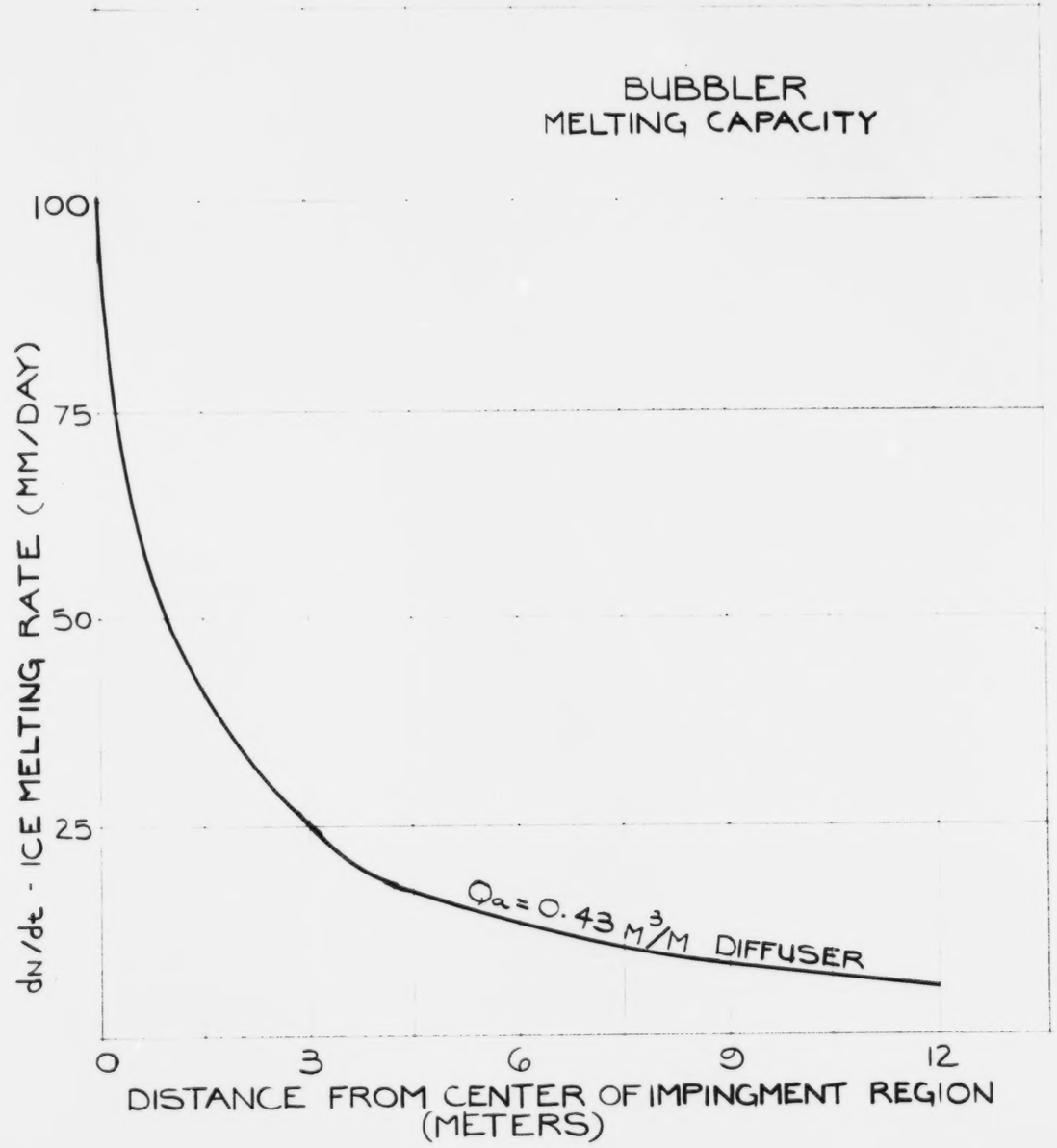
0 5 10 15 20 25 30 35 40 45 50

0 10 20 30 40 50 60 70 80 90 100 10 120 130 40 150 160 170 180 190 200

FREEZING DEGREE DAYS (°C-DAY)

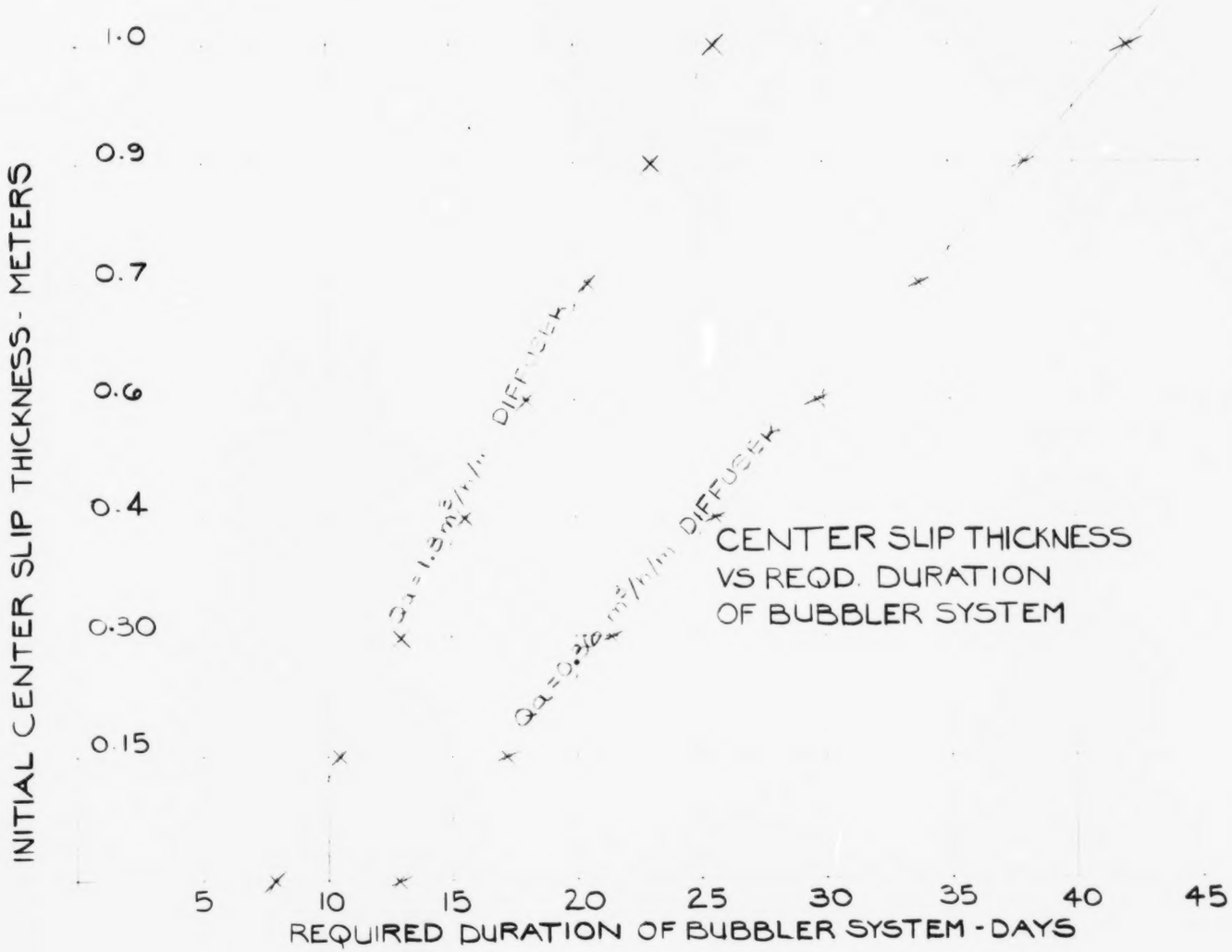
DWG N° 505

PROJECT 80-211-01
AIR BUBBLER SYSTEM



DWG. Nº 506

PROJECT 80-211-01
AIR BUBBLER SYSTEM



DWG. Nº 507